

# INFLUENCE OF AIRFIELD STRUCTURES AND COMPLEX TERRAIN UPON SIMULATED LOCAL WIND FIELDS

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## ABSTRACT

The High Resolution Wind model, HRW, is used to simulate the influence and effects that complex terrain and land morphology features such as airfield structures have on wind fields. Fort Hunter-Liggett airfield is the site selected for this study and the high resolution, terrain elevation data base, PEGASUS, for Fort Hunter-Liggett is used as the digitized terrain input for the model. Structures such as three **airfield** buildings prescribed for other aspects of the study are defined for model input. Two contrasting sets of meteorological conditions are identified from Fort Hunter-Liggett's data archives. Meteorological fields of wind vectors and wind streamlines are produced by HRW. Both scenarios exhibit a changing wind field over the variable mountainous terrain flanking each side of the valley. Wind fields in the valley's smoother terrain are relatively uniform except in and about the airfield's buildings. An additional analysis is also applied to further quantify and interpret the influence and effects of terrain and structures upon the localized wind fields as well as for applications such as the release of smoke and obscurants for a **battlespace** environment. Results show that wind fields are readily influenced by structures to cause accelerations and decelerations or change of direction within a few hundred meters downwind. The HRW model clearly detects and responds to the presence of structures on terrain that is also variable in nature.

## 1. INTRODUCTION

US Army Research Laboratory's (**ARL**) High Resolution Wind model (**Cionco** 1985), HRW, is used to simulate the interactions and effects that complex terrain and land morphology features, such as buildings, have on wind fields over an airfield. Fort Hunter-Liggett's airfield in California is the site selected for this study. The high resolution terrain elevation data base, PEGASUS, for Fort Hunter-Liggett is used as the digitized terrain input for the model. Three **airfield** buildings prescribed for other aspects of the study are defined also for model input. Two contrasting sets of meteorological conditions are identified from Fort Hunter-Liggett's data archives. Meteorological fields of wind vectors and wind streamlines are numerically simulated by HRW. An additional analysis (**Cionco** and Byers, 1993) is also applied to further quantify

the influence and effects of terrain and structures upon the localized wind fields as well as for numerous applications such as the release of smoke and obscurants. Examples of the simulated wind fields are shown for the full domain and also for the limited area focused and **magnified** at the airfield site.

## 2. APPROACH

Several simulation tools are identified and two differing scenarios for analysis are established. The tools to be used are a high-resolution wind flow model/code, digitized terrain elevation, building structure data sets, and meteorological data for model initialization. ARL's HRW code is selected to simulate the desired meteorological fields. Fort Hunter-Liggett airfield is the site selected for this simulation study. The PEGASUS high-resolution, terrain elevation data base is used as the digitized terrain elevation input for the code. Figure 1 shows the terrain as contoured values ranging from 280 m to 420 m. The **airfield** runway and buildings are also plotted in this figure. The three airfield buildings are shown enlarged in figure 2 where the two hangers and control tower are located northwest of the apron for Scenario A. Note that for Scenario B, the buildings are relocated to the southeast of the apron.

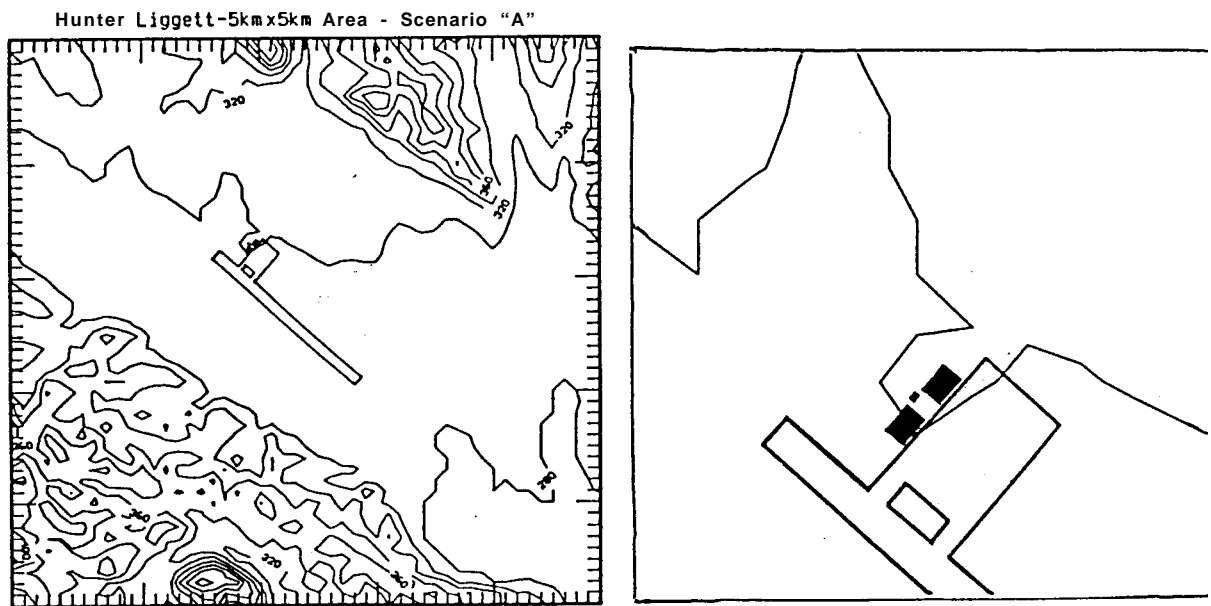


Figure 1. Contoured topography of the 5Km x 5Km Ft. Hunter-Liggett domain including the **airfield** runway, apron, and buildings.

Figure 2. An enlarged image of the **airfield** apron and buildings for Scenario A. Note that for Scenario B the buildings are located along the southeast edge of the apron.

Two contrasting sets of meteorological conditions are identified from the Fort **Hunter-Liggett** Meteorological Team’s data archives and presented in Table 1.

TABLE 1. METEOROLOGICAL CONDITIONS

VARIABLES:	SCENARIO A	SCENARIO B
WIND SPEED	<b>5.0 M/s</b>	<b>2.7 M/S</b>
DIRECTION	137.5°	311.5°
TURBULENCE	MODERATE	LOW
STABILITY	UNSTABLE	STABLE
SUN ANGLE	HIGH	LOW

Scenario A is a late morning condition with a high sun angle and slightly unstable atmosphere with a wind speed of 5.0 m/s from the southeast (up valley) and higher turbulence levels. Scenario B is prescribed to be for a stable atmosphere just at sunrise with a low sun angle and a wind speed of 2.7 m/s from the northwest (down valley) and lower turbulence levels. Both scenarios are for the same day.

### 3. THE SIMULATION MODEL

Two models are available at the US ARL, to analyze flow fields over complex terrain and land morphology features. They are (1) the High-Resolution Wind Model, HRW, and (2) the Canopy-Coupled to the Surface Layer Model, **C-CSL** (**Cionco**, 1985). The High Resolution Wind Model, HRW, is chosen to simulate the influence and effects complex terrain and morphology features (buildings) have on wind fields. These simulations are also used for the terrain effects analysis described herein.

#### 3.1 The wind model

HRW is a two-dimensional, diagnostic, time independent model that simulates the wind flow over a grided area of 5 km by 5 km with a preferred spatial resolution of 100 meters. The computational domain size can range from 2 km by 2 km to 20 km by 20 km with grid resolutions of 40 meters to 400 meters respectively. The thickness of the computational layer is defined as 1/10th the magnitude of the grid size.

Beginning with initial uniform wind and temperature fields, the simulation results are obtained by a direct variational relaxation of the wind and temperature fields in the surface layer. The solution is reached when the internal constraint forces imposed by the warped terrain surface, thermal structure and the requirement for flow continuity are minimized. The procedure makes use of Gauss’ Principle of Least Constraints (Lanczos, 1962) which requires these forces to be minimized in order to satisfy the equations of motion. When applied to the surface layer, this

procedures

### 3.1.1

For the application, a grid size of 100 meters is used for the two simulation cases. The grid intervals in x and y coordinates for the entire area of interest. Information such as building structures can also be used as input. The initialization of the model requires, as a minimum: wind speed and direction and pressure from one local surface station at the 10 m level and one temperature and pressure-height profiles to estimate the atmospheric stability. Note that data from only one site are used to start the simulation. Additional soundings and surface stations can also be used for initialization.

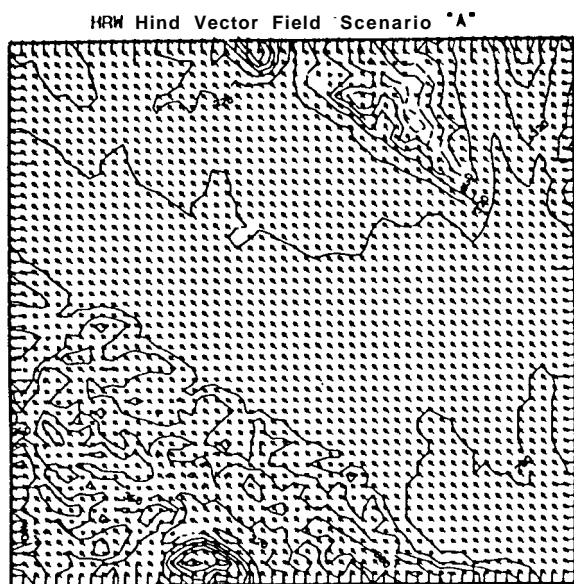
### 3.1.2 Simulated

The resulting output is in the form of list and binary archive files containing simulated values for the wind and other meteorological parameters. Simulated x,y fields of the u and v wind components and their vector field, streamline flow, potential temperature, friction velocity, the power law exponent, and Richardson's Number are computed. Scenario A's simulated vector field and streamline flow field are shown in figures 3 and 4. For the full domain, vector magnitudes, in general, range from 4.5 to 5.5 m/s. In the mountainous areas and immediately over the airfield structures noted as white (no vector is plotted) where speeds are accelerating 110 to 150% of the input velocity (m/s) in figure 3. Directionally, the streamlines show changes in figure 4 throughout the domain, but most notably in the mountainous areas and a slow sweeping change upvalley. The simulated vector field and streamline flow field for Scenario B are presented in figures 5 and 6. In general, more areas of accelerating speeds are occurring noted again by the 'white' areas over the mountainous areas, along the terrain contours, and above the buildings in figure 5. Locations of greatest acceleration are generated in the midst of the heavily-contoured terrain northeast and southwest of the valley. Streamline patterns show changes everywhere in figure 6 with areas of convergence and divergence and a distinct directional response to the presence of the airfield structures.

## 3.2 Adverse impact analysis

Our terrain effects analysis method (Cionc and Byers, 1993) provides a means to interpret the meteorological output from HRW for a customized usage and assessment. The method uses the microscale wind flow model output and a visualization technique. The method provides a simple means for quick and easy quantification of the wind effects and identifying those areas that may be adversely or favorably affected by or impacted upon during your field activities. An appropriate set of criteria for the activity being analyzed is applied to these simulated fields such as wind to determine the degree that these terrain effects may or may not impact on your field operations. Each type of operation, study, or experiment has its own particular criteria that you, the user, must establish.

The method involves analyzing the newly simulated field in



Julian Day: 351 Time: 1045  
 Wind Direction : 137.5 Deg  
 Wind Speed 5.0 m/s

Figure 3. The simulated field of wind vectors for Scenario A (upslope flow)

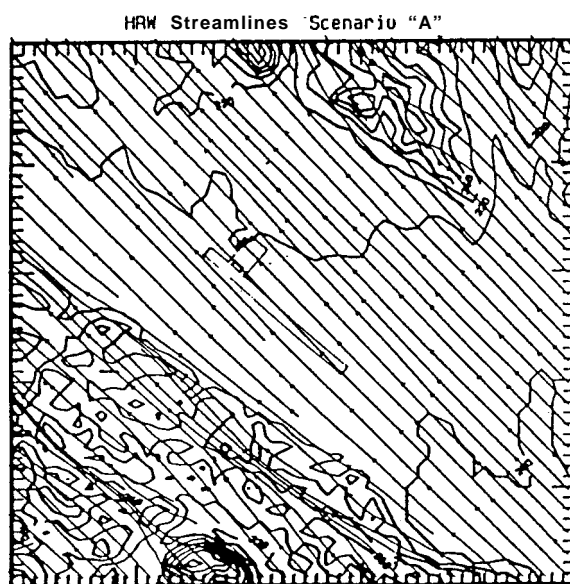
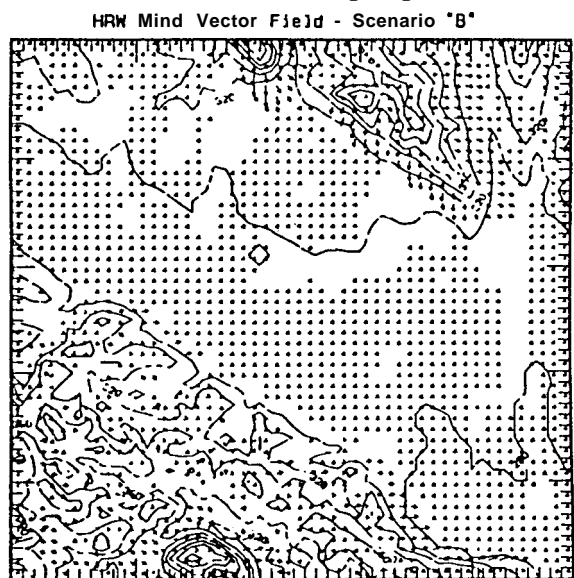


Figure 4. Streamline field of wind flow for Scenario A.



Julian Day: 351 Time: 0745  
 Wind Direction: 311.5 Deg  
 Wind Speed 2.7 m/s

Figure 5. The simulated field of wind vectors for Scenario B (downslope flow)

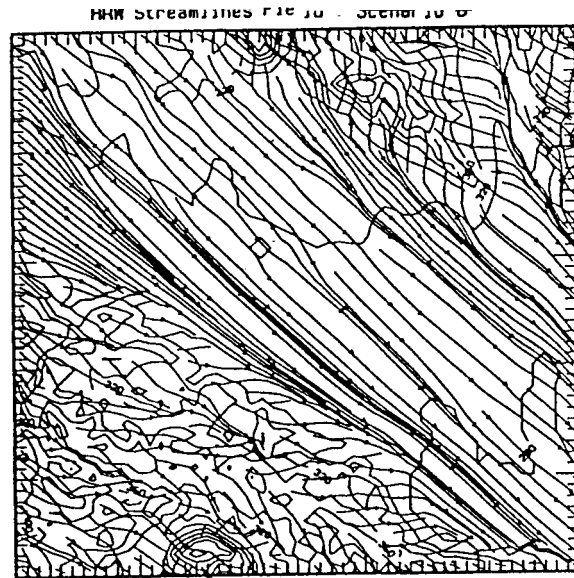


Figure 6. Streamline field of the simulated wind flow for Scenario B.

$$\text{EFFECT} = \text{FINAL SIMULATED FIELD} - \text{INITIAL FIELD}$$

More specifically, the wind speed effect and the wind direction effect are determined separately, frost. The Wind speed Effect ( $E_{ws}$ ) is the difference between the values for the final simulated wind speed field ( $S_s$ ) and the initial wind speed field ( $S_i$ ):

$$E_{ws} = S_s - S_i$$

The Wind Direction Effect ( $E_{wd}$ ) is the difference between the values for the final simulated wind direction field ( $D_s$ ) and the initial wind direction field ( $D_i$ ):

$$E_{wd} = D_s - S_i$$

A qualitative assessment of the Total EFFECT can be made, fiist, by combining the effects of the two difference fields. To quantify these effects, a set of appropriate operational criteria is established for the phenomena under study or test. Three levels of EFFECT are defined for aerosol diffusion studies and field experiments: Light, Moderate, and Severe.

The results can be visualized by next constructing color-coded maps (not provided herein) showing the degree of the wind effects. The effect/ impact can then be quickly and easily assessed when the terrain features, vector or streamline field of the domain are added to these maps. Examples of terrain and structures effects analyses are given for Scenario A in figure 7 and Scenario B in figure 8 as derived from simulated high-resolution wind fields. Both speed and directional effects are shown here. Although the gray scale rendition of the original **color**-coded figures is marginal, one can discern the areas of light, moderate, and severe impacts for speed and direction as dark, white, and heavy black boxes and no hatching (no symbol), hatching, and cross-hatching areas respectively. For Scenario A in Figure 7, the analysis field generally exhibits a light impact whereas the white areas indicate a moderate impact and the heavy black boxes within the white areas are severe impact locations. The hatch patterns denote areas of moderate directional impact. For Scenario B in figure 8, the valley is now a light to moderate impact area and the mountainous slopes are producing moderate to severe adverse terrain effects upon both speed and direction.

#### 4. RESULTS

Zooming into a 1 Km by 1 Km area to inspect the building's effects upon the flow, we note that HRW is capable of detecting and responding to the presence of structures positioned on the smoother valley floor. In the vicinity of the buildings, Scenario A shows changes in wind speed with only minor directional changes in figure 9 and Scenario B exhibits both wind speed acceleration and direction changes in figure 10. Recall that the white areas are for vectors depicting notable accelerations. The adverse impact analysis readily depicts increased interactions and building effects in figures 11 and 12. The impact of the buildings for Scenario A (figure 11) is moderate (white areas) for wind speed accelerations, but only light (no hatching pattern) for directional changes. For Scenario Bin figure 12, the impact of the buildings is notably moderate for both wind speed (white areas) and direction (hatching pattern).

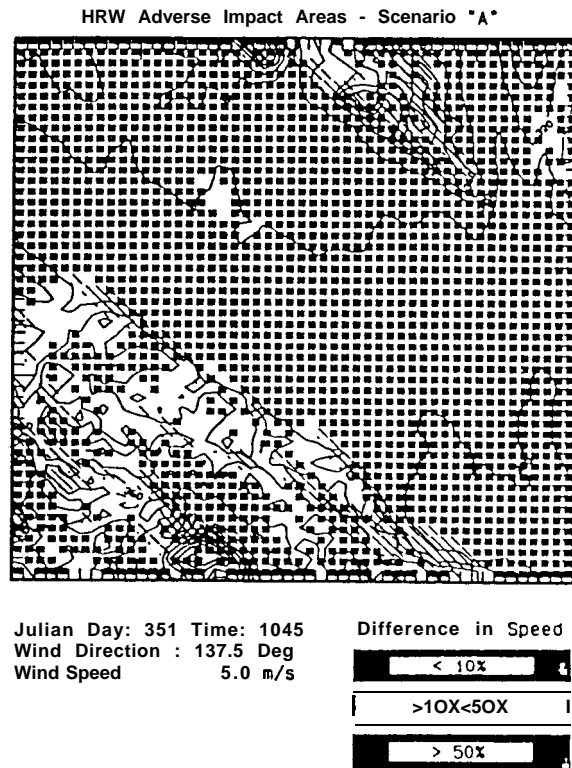


Figure 7. Terrain effects analysis depicting areas of adverse impact for Scenario A.

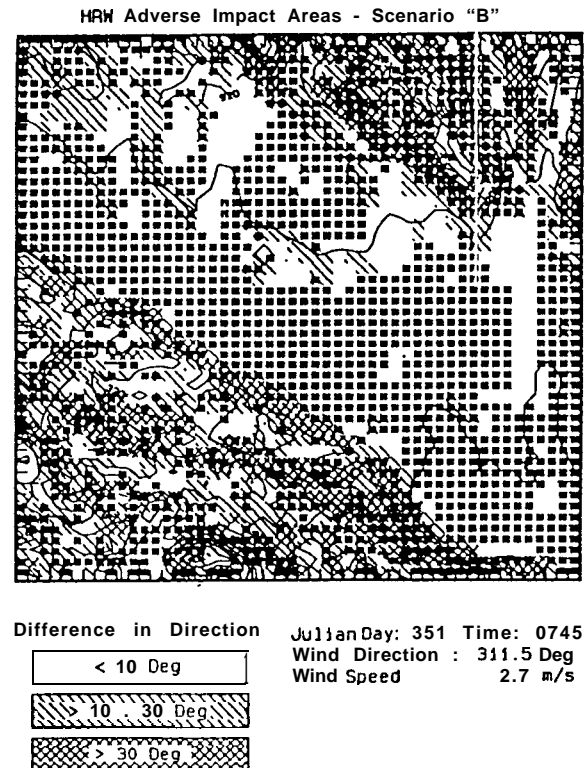


Figure 8. Terrain effects analysis depicting areas of adverse impact for Scenario B.

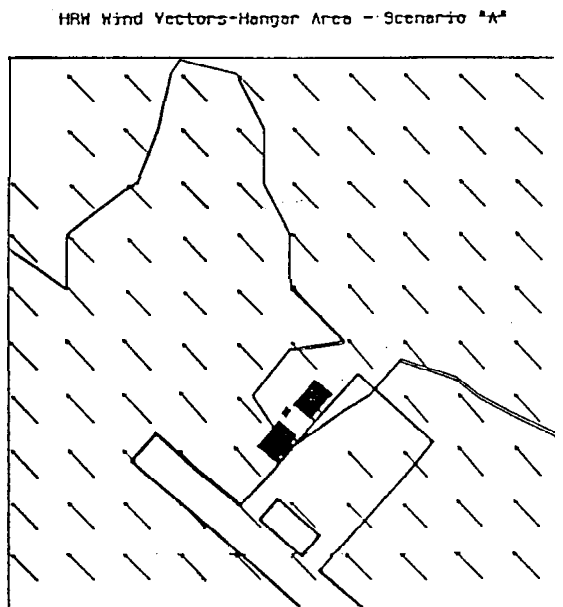


Figure 9. Close-up, localized view of the simulated vector field in and about the airfield for Scenario A.

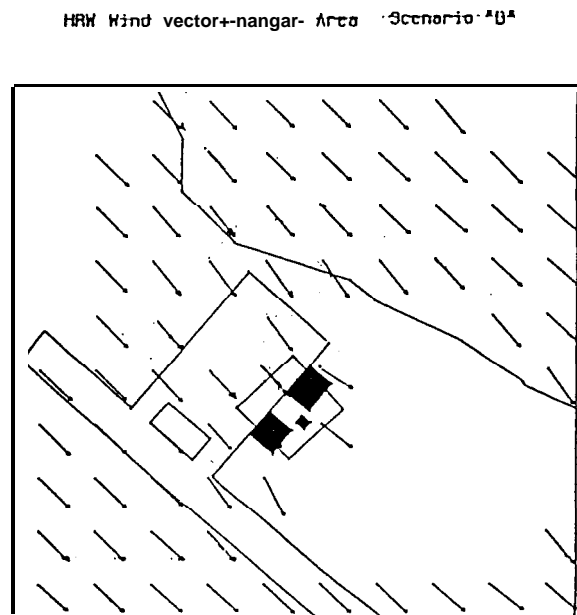


Figure 10. Close-up, localized view of the simulated vector field in and about the airfield for Scenario B.

HRW Adverse Impact-Hongar Area - Scenario "A"

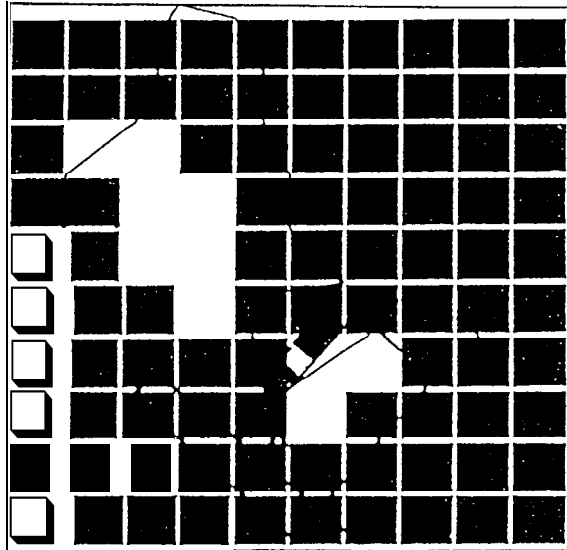


Figure 11. Close-up, localized view of the building effects for Scenario A.

HRW Adverse Impact-Hongar Area - Scenario "B"

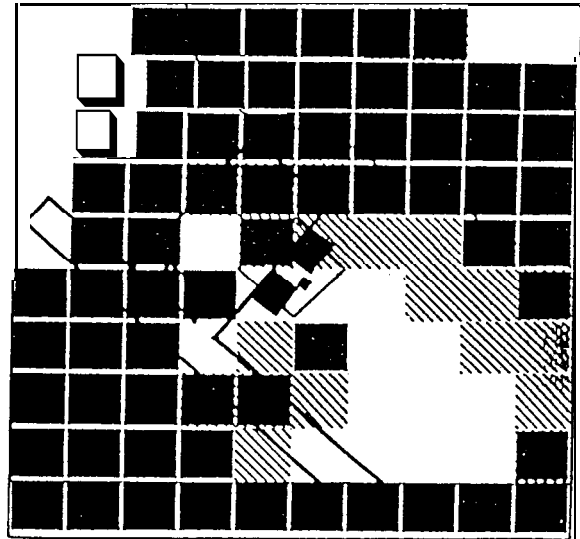


Figure 12. Close-up, localized view of the building effects for Scenario B.

## 5. CONCLUSIONS

The HRW model clearly detects and responds to the presence of structures in a terrain domain that is also variable in nature. For the full domain, both scenarios exhibit a changing wind field over the variable mountainous terrain flanking each side of the valley. Wind fields in the valley's smoother terrain are relatively uniform except in and about the airfield's buildings. A closer look at Scenario A shows that simulations produce both terrain and building influences and effects on wind speed and direction. Scenario B with the lower speed regime shows a greater degree of influence and effect particularly in and about the buildings than did the Scenario A simulations.

An additional analysis is also applied to further quantify the influence and effects of terrain and structures upon the localized wind fields for applications such as the release of smoke and obscurants. Results of the adverse impact analysis also show that both adverse and favorable impact areas are readily identified as speed or direction changes within a few hundred meters downwind of structures and terrain features. A release of smoke and obscurants in these two contrasting scenarios clearly will be influenced and affected by the interaction with both variable terrain and **airfield** structures.

## ACKNOWLEDGEMENT

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